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FULL TITLE:

Woven Endobridge (WEB) Device as a Re-Treatment Strategy after Unsuccessful Surgical Clipping

SHORT TITLE:

WEB Device after Unsuccessful Surgical Clipping

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Woven Endobridge (WEB) Device as a Re-treatment Strategy after Unsuccessful Surgical Clipping

ABSTRACT

BACKGROUND

Surgical clipping of intracranial aneurysms is typically robust and durable. However, residual aneurysmal components may be seen after clipping. Furthermore, there may be occasional aneurysmal recurrence. These are both clinically relevant because subarachnoid hemorrhage after clipping is a rare but important event. The rationale for any treatment is to substantially lower the future risk of hemorrhage. Small series have demonstrated coiling as a re-treatment strategy after unsuccessful clipping, but none have explored the feasibility of Woven Endobridge (WEB) implantation.

CASE DESCRIPTION

We examined the feasibility of WEB implantation as second-line treatment for wide-necked residual aneurysms after unsuccessful clipping. We also recorded the safety and efficacy in this small series of 6 patients. To determine safety, we measured the modified Rankin Scale (mRS) before and after the procedure, and at two later time-points (mean follow-up 5 months and 15 months). To determine efficacy, we obtained radiographic aneurysm occlusion outcomes (including WEB Occlusion Scale) at these two time-points. Four middle cerebral artery and two anterior communicating artery complex aneurysms were treated with WEB implantation showing feasibility in 6/6 (100%) cases. Follow-up at 15 months demonstrated no change from pre-procedural mRS and there were no other complications. There was adequate occlusion in 5/6 (83%) cases.

CONCLUSIONS

WEB implantation provided a feasible option in this challenging re-treatment scenario. We emphasize that this is a small series and prospective data is required to make outcome inferences for this population. Nonetheless, we observed no complications and high adequate occlusion rates.

ABBREVIATION LIST

CT = computed tomography

CTA = computed tomography angiography

DSA = digital subtraction angiography

MDT = multi-disciplinary team

MRA = magnetic resonance angiography

MRI = magnetic resonance imaging

SL = single layer

TOF = time-of-flight

WEB = Woven Endobridge

WFNS = world federation of neurosurgeons

WOS = WEB Occlusion Scale

INTRODUCTION

Surgical clipping of intracranial aneurysms is typically robust and durable, however, a residual aneurysmal component may be seen after clip placement in up to 4-8% of cases.¹⁻⁶ Furthermore, in 1-3% of cases there may be aneurysmal recurrence.⁵⁻⁷ These are both clinically relevant occurrences because there is a persistent risk of rupture or re-rupture.^{3,5,8,9} Subarachnoid hemorrhage from remnants after surgical clipping is poorly quantified, but may occur in 0.8% of cases per annum.¹⁻³ The rationale for any treatment is to substantially lower the future risk of hemorrhage and therefore re-treatment of residual or recurrent aneurysms is frequently indicated. A third scenario for re-treatment occurs when a clip cannot be placed safely and the surgeon judiciously elects to abandon the procedure.¹ In all three scenarios, re-treatment with clipping appears to be associated with an increased rate of complications.^{1,10} Endovascular re-treatment appears to have a lower rate of complications, and has become more common in the last two decades.⁹ However, many aneurysms that recur are wide-necked and are therefore challenging to treat by endovascular coiling alone because of the risk of coil protrusion into the parent vessel.^{11,12} A definitive re-treatment strategy has not been established and aneurysms are managed on a case-by-case basis. In this context, the Woven Endobridge (WEB; Sequent Medical, Çaliso Viejo, California) device might emerge as an endovascular re-treatment option in selected cases. Indeed, it has recently been shown in a small series that re-treatment of recurrent, previously-coiled aneurysms with WEB implantation is feasible and may be safe and effective.¹³ The WEB is a nitinol, braided-mesh, self-expanding, intrasaccular flow-disrupter with a three-dimensional structure primarily designed to occlude wide-neck intracranial aneurysms. The second-generation WEB consists of a single layer compartment that impedes aneurysmal neck blood flow resulting in intra-aneurysmal thrombosis and subsequent endothelialization. Since its introduction in 2011,

several single arm studies have shown that the WEB appears safe (low morbidity and mortality) and effective (high adequate occlusion rates) when used as a first-line implant to treat wide-neck ruptured and unruptured aneurysms.¹⁴⁻²¹ Whilst small series have demonstrated coiling as a re-treatment strategy after unsuccessful clipping,⁹ no series has explored the feasibility of WEB implantation. We describe the feasibility of WEB for re-treatment of wide-neck aneurysms after surgical clipping has been unsuccessful. We report the combined experience of four centers and present safety (morbidity and mortality) and efficacy (occlusion rates) outcomes.

CASE DISCUSSION

Methods and materials

We searched medical records for patients with residual aneurysms that were treated with WEB after unsuccessful surgical clipping between January 2014 and January 2016 at six UK hospitals. For each patient included in the study, we retrospectively analyzed the electronic medical records; pre-procedural, procedural and post-procedural images; as well as procedural records. We collected demographic, radiological and clinical data on an intention-to-treat basis. The presence of a residual aneurysm was confirmed on follow-up digital subtraction angiography (DSA) and/or 3D time-of-flight MRA (3D TOF MRA). The diameter of any residual aneurysmal sac and neck were measured.

WEB implantation for all cases was chosen following a consensus decision at a neurovascular multi-disciplinary team meeting which included interventional neuroradiologists and neurovascular surgeons. Anatomical characteristics (including location, a high neck-to-sac ratio and a wide neck), safety and technical concerns, and the role of anti-platelets, were the main factors leading to WEB implantation in preference to coiling, stent-assisted coiling or further clipping.

Interventional neuroradiologists performed all procedures under general anesthesia using a femoral approach. Anticoagulation and anti-platelet therapies were administered according to local institutional protocol.

To determine safety, we recorded the modified Rankin Scale (mRS) before and after the procedure and at follow-up at two later time points. Ischemic and hemorrhagic complications were analyzed. Imaging follow-up was performed with DSA (with

additional cone-beam CT angiography in some centers), or 3D time-of-flight (TOF) MRA (AERA 1.5 T, Siemens Healthcare GmbH, Germany) with TR 25 ms, TE 7 ms, flip angle 25 (with ramped pulse), matrix 241 x 256, field of view 18 x 18 cm, and slice thickness 1.4 mm (reconstructed to 0.5 mm). To determine efficacy, aneurysm occlusion status was classified using the WEB Occlusion Scale (WOS).²² Opacification of the WEB device recess (WOS 2) was considered complete occlusion.

Written informed consent was obtained from all patients. We received written confirmation from the Research and Innovation Department at King's College Hospital that the UK's Health Research Authority does not require review by a Research Ethics Committee given the nature of the retrospective study using de-identified data. The study was performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and its later amendments.

Results

Six patients from four hospitals with residual bifurcation aneurysms after unsuccessful surgical clipping were re-treated with WEB implantation. The causes for unsuccessful surgical clipping were: the decision to abandon the procedure due to the presence of a mixed atheromatous and calcified plaque at the aneurysmal neck extending into the temporal M2 segment, which might cause emboli as well as temporal M2 segment occlusion if clipped (Patient 1; Figure 1); inability to create a dissection plane surrounding the aneurysm as it was adherent to the surrounding structures making clip placement technically challenging and unsafe (Patient 2); inability to safely dissect free the origins of the M2 branches which arose from the aneurysm neck increasing the risk of occluding an M2 branch (Patient 3). These three aneurysms were wrapped with muslin pending further re-treatment. Suboptimal clip placement resulted in inadvertent incomplete

clipping in Patients 4 (Figure 2), 5 (Figure 3), and 6 (Figure 4) despite indocyanine green angiography (ICGA) appearing to show satisfactory clip positioning. In patient 4 the procedure was complicated by impaired visualization of the neck branches and a bloody operative field. Baseline patient characteristics and initial aneurysm features are summarized in Table 1.

The mean time between unsuccessful surgical intervention and re-treatment with WEB implantation was 37 days (range 2-90 days) (Table 2). A single WEB Single-Layer (SL) device was successfully implanted in all cases attempted. Pre-, intra-, and postoperative antiplatelet and anticoagulant therapy was managed in each center in accordance with the local institutional protocol at the time (Supplementary Table 1).

There were no periprocedural thromboembolic or hemorrhagic complications (both 0%, 0/6; Table 3). Periprocedural vasospasm was noted without clinical consequence in a single patient. The first and second clinical and radiographic follow-up time points were at 5 months (mean, range 3-6 months) and 15 months (range 8-24 months) after the procedure respectively. There was no change in the pre-procedural mRS in all 6 cases periprocedurally and at first and second follow-up time points. In particular, no patient died or became dependent (mRS 3-6) over the follow-up period. At the second follow-up time point, three patients had complete occlusion of the aneurysm (50%, 3/6; WOS 2), two patients had a neck remnant (33%, 2/6; WOS 3) and one patient a sac remnant (17%, 1/6, WOS 4). The one patient with a sac remnant had a neck remnant at the first follow-up (3 months) which subsequently became a sac remnant at second follow-up (8 months) at which point they underwent further re-treatment using coils and an Aneurysm Neck

Reconstruction Device (PulseRider, Pulsar Vascular, San Jose, California) in order to achieve complete occlusion.

Discussion

Summary of findings

We showed that WEB implantation was a feasible option in the challenging scenario where a wide-necked aneurysm or wide-necked aneurysmal component requires re-treatment after unsuccessful surgical clipping. We observed that there were no complications and high adequate occlusion rates.

Strengths and weaknesses

To the best of our knowledge this is the first description of WEB re-treatment after unsuccessful surgical clipping.⁹ Small series case reports such as ours inevitably have inherent limitations and demonstrate feasibility only. Our series was retrospective and contained only a small number of patients. Data from a large prospective study is required to make outcome inferences for this population. However, it is challenging to obtain optimal data as shown in a recent systematic review of coiling re-treatment after clipping where the mean series size for studies was 8 (range 3-21) and all cases were retrospective.⁹ Furthermore, when stent coiling was assessed specifically, there were only five cases pooled from two series.⁹ Therefore, given the paucity of data regarding re-treatment, our small series is likely to contribute to the interventional neuroradiology literature. A strength of our series is that four hospitals contributed cases. Furthermore, all endovascular cases from six hospitals with large neurovascular practices were reviewed for inclusion, which represented approximately 35% of UK practice (the total denominator of endovascular cases was two orders of magnitude more than the number of cases included in our series). Therefore, our cases are likely to be reasonably representative of current UK practice for this uncommon re-treatment strategy. Other limitations are that follow-up was relatively short (mean follow-up 5 months and 15

months) and 3D TOF MRA was used for follow-up in two cases. Whilst a recent meta-analysis has shown that MRA (whether using TOF MRA or CEMRA) is a reliable modality for the follow-up of aneurysms treated using a variety of endovascular techniques (including stent-assisted coiling and flow diverters),²³ it is possible that there was a reduction in sensitivity compared to DSA in detecting aneurysmal remnants according to two small retrospective studies where WEB susceptibility was described.^{24,25} It is conceivable that the adequate occlusion rates observed in our series could be lower. However, in most cases included in the two small retrospective studies, first-generation (double-layer) WEBs were used, MRA was performed at a higher field strength (3 T) and a different MRA technique was employed, all of which differed from the current series. Furthermore, in our two cases, other sequences (T1- and T2-weighted) and scan planes (multiplanar reformat) were reviewed and in all first treatment WEB implantations we have yet to discover a false negative remnant after a subsequent DSA. It is also noteworthy that cross-sectional MRI confirmed occlusion because a decrease in the size of the aneurysm sac on cross-sectional imaging appears to be the single most consistent sign of durable aneurysm occlusion (likely implying full endothelialization of the device construct and secondary exclusion of the aneurysm from the parent circulation).^{26,27}

Comparison with studies worldwide

In our series, no thromboembolic or hemorrhagic complications occurred. As is inherent in small series case reports, statistical comparison cannot be made with other studies. Nonetheless, we observe that thromboembolic events (including asymptomatic ones) occurred in 14% of patients in the pooled results of three multicenter studies (WEBCAST, French Observatory, WEBCAST-2) investigating WEB for the primary treatment of unruptured aneurysms¹⁴ and in 8% of patients in a recent meta-analysis of 588 aneurysms

(127 ruptured) treated with WEB.¹⁶ In a recent series, 16 patients underwent re-treatment of recurrent, endovascularly-treated aneurysms with WEB implantation and there were thromboembolic events in 6%.¹³

The morbidity and mortality rates were 1% and 0% respectively in the three multicenter studies combined;¹⁴ 4% and 1% respectively in the meta-analysis of 588 aneurysms;¹⁶ and 6% and 0% respectively in the re-treatment series.¹³ In our series, the outcomes were similar (both 0%).

We evaluated aneurysm occlusion with the WOS, which has been used as a measurement scale in three large prospective multicenter WEB studies.¹⁴ Complete occlusion (WOS 2), neck remnant (WOS 3), and aneurysm sac remnant (WOS 4) at follow-up imaging were observed in 50%, 33%, and 17% of all aneurysms respectively at a mean follow-up of 15 months. Owing to the small size of our sample, it was not possible to perform statistical analyses of aneurysm factors, such as the influence of the sac or neck size, or surgical factors (incomplete or no clip placed) that might influence occlusion status, but no association seemed apparent. Whilst re-iterating the limitations of comparison with other studies, we observe that the occlusion rates of our series appeared similar to the three multicenter studies combined in which complete occlusion, neck remnant, and sac remnant rates were 53%, 26%, and 21% at 12 months respectively.¹⁴ In the re-treatment series, the rates were 33%, 40% and 27% at 12 months. These occlusion rates also appeared similar to the recent meta-analysis of 588 aneurysms,¹⁶ where the adequate occlusion rate after a median of 7 months follow-up was 84% for unruptured and 85% for ruptured aneurysms, compared to 83% in our series.

Study explanations and relevance from a national and international perspective

We have shown the feasibility of an additional re-treatment strategy after unsuccessful clipping by using WEB implantation. In some scenarios this may be preferable to clipping, coiling, or the use of stents with or without flow diverting properties.

Anatomical or technical difficulties are likely to be the cause for unsuccessful clipping at the first treatment, making re-treatment with clipping intrinsically unfavourable.²⁸ Furthermore, adhesions surrounding the aneurysm, adjacent tissues or original clip may complicate re-treatment with clipping, particularly when there has been a lengthy interval between the surgeries.^{1,29} The morbidity and mortality rates are at least 7% (mRS score > 2) and 5% respectively.^{1,3,10} Intraoperative rupture also appears to be more common during re-treatment.¹⁰

The same disadvantages relating to coiling, stent-assisted coiling or flow diversion, that led the neurovascular multi-disciplinary team to recommend clipping at first treatment persisted when re-treatment was discussed. Anatomical characteristics including a high neck-to-sac ratio, a wide neck and being located at a bifurcation, limited the endovascular options which would typically require temporary balloon assistance as a minimum, or more often a stent (or two) to avoid coil protrusion into the parent vessel. Procedures using such adjuncts in wide neck bifurcations aneurysms can be technically complex and, compared to coiling alone, appear to have a higher periprocedural complication rate and a lower adequate occlusion rate, which at 6-18 months may be 63% or lower.^{30,31} Furthermore, there is an increase in procedural time and radiation dose compared to standard coiling. Two aneurysms were also partially thrombosed (Patients 1 and 2); the implication of re-treatment with coiling (whether balloon or stent-assisted) is that there may be a higher rate of recanalization than in non-thrombosed cases.³² Flow diversion has been used rarely in bifurcation aneurysms and the long-term effects on covered

bifurcation branches and perforating arteries is not yet fully understood.³³ Importantly, there are risks associated with prolonged dual anti-platelet use which is required after stent-assisted coiling or flow diversion. Following subarachnoid hemorrhage, the risk of periprocedural complications associated with dual anti-platelet use is particularly high.³⁴ An additional disadvantage of coiling that occurs after clipping is that treatment appears to be more technically challenging, possibly due to perianeurysmal scarring increasing the aneurysm wall rigidity.³⁵

At the time when this series was performed, the neurovascular multi-disciplinary team had recommended clipping as first treatment, and not WEB implantation, because there was insufficient outcome data for WEB implantation of wide-necked bifurcation aneurysms compared to clipping (Patients 1-4) (neither WEBCAST, WEBCAST 2 or French Observatory studies had been published¹⁴ nor had UK NICE guidelines been published approving routine first line use of WEB³⁶). After unsuccessful clipping, because the disadvantages of performing coiling, stent-assisted coiling or flow diversion persisted and because re-treatment with clipping became high risk, a cost-benefit analysis by the neurovascular multi-disciplinary team favored WEB implantation as a re-treatment strategy. In two patients WEB implantation at first treatment was less suitable due to the aneurysm morphology (Patient 5; Figure 3) or entirely unsuitable due to size (Patient 6; Figure 4) so this option was never considered by the neurovascular multi-disciplinary team initially. However, after clipping the remodeled aneurysm inadvertently allowed re-treatment with WEB implantation.

In the two cases where there was partially thrombosed aneurysm (Patients 1 and 2), the proximal component of the aneurysm was not thrombosed and the size and morphology were suitable for WEB “corking” of this proximal component (Figure 1).³⁷ At 6 and 18

months, there was adequate occlusion in these two aneurysms. Therefore, we have also shown in this series that WEB “corking” of the proximal component of an aneurysm which is partially thrombosed is a feasible treatment option. It is noteworthy that the selective targeting of the proximal component does not contradict a report which showed that WEB is a suboptimal treatment for thrombosed aneurysm sacs in general.³⁸

CONCLUSIONS

We showed that WEB implantation was a feasible option in the challenging scenario where a wide-necked aneurysm or wide-necked aneurysmal component requires re-treatment after unsuccessful surgical clipping. We observed that in our series the implantation was safe (no morbidity and mortality) and effective (high adequate occlusion rates). Technical, radiological and clinical outcomes for this indication appear similar to studies where WEB implantation was used as the primary treatment of aneurysms. We highlight that despite the increasing evidence from prospective studies, not all neurovascular multi-disciplinary teams agree that WEB implantation should be used even for first line treatment.³⁹⁻⁴¹ We emphasize that this is a small series and prospective data from a larger cohort with longer follow-up would be optimal to generate higher level evidence and outcome inferences for this population. If future higher level evidence shows outcomes to be similar to our observations, potential indications for re-treatment with WEB implantation might resemble the indications for re-treatment after coiling:¹³ (1) bifurcation aneurysm; (2) aneurysm or aneurysmal component after clipping; (3) and configuration suitable for WEB implantation.

Declarations of interest: none

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REFERENCES

1. Drake CG, Friedman AH, Peerless SJ. Failed aneurysm surgery: reoperation in 115 cases. *J Neurosurg.* 1984; 61: 848–856.
2. Feuerberg I, Lindquist C, Lindqvist M, Steiner L. Natural history of postoperative aneurysm rests. *J Neurosurg.* 1987; 66: 30–34.
3. Lin T, Fox AJ, Drake CG. Regrowth of aneurysm sacs from residual neck following aneurysm clipping. *J Neurosurg.* 1989; 70: 556–560.
4. Sindou M, Acevedo JC, Turjman. Aneurysmal remnants after microsurgical clipping: classification and results from a prospective angiographic study (in a consecutive series of 305 operated intracranial aneurysms). *Acta Neurochir (Wien).* 1998; 140: 1153–1159.
5. David CA, Vishteh AG, Spetzler RF, Lemole M, Lawton MT, Partovi S. Late angiographic follow-up review of surgically treated aneurysms. *J Neurosurg.* 1999; 91: 396–401.
6. Burkhardt J-K, Chua MHJ, Weiss M, Do AS-MS, Winkler EA, Lawton MT. Risk of Aneurysm Residual Regrowth, Recurrence, and de Novo Aneurysm Formation After Microsurgical Clip Occlusion Based on Follow-up with Catheter Angiography. *World Neurosurg.* 2017;106:74-84.

7. Tsutsumi K, Ueki K, Morita A, Usui M, Kirino T. Risk of aneurysm recurrence in patients with clipped cerebral aneurysms: results of long-term follow-up angiography. *Stroke*. 2001;32(5):1191-1194
8. Bendok BR, Ali MJ, Malisch TW, Russell EJ, Batjer HH (2002) Coiling of cerebral aneurysm remnants after clipping. *Neurosurgery* 51(3):693–697; discussion 697–698.
9. Della Pepa GM, Bianchi F, Scerrati A, et al. Secondary coiling after incomplete surgical clipping of cerebral aneurysms: a rescue strategy or a treatment option for complex cases? Institutional series and systematic review. *Neurosurg Rev*. 2019;42(2):337-350
10. Gianotta SL, Litofsky NS. Reoperative management of intracranial aneurysms. *J Neurosurg*. 1995; 83: 387–393.
11. McDonald JS, Carter RE, Layton KF, et al. Interobserver variability in retreatment decisions of recurrent and residual aneurysms. *AJNR Am J Neuroradiol*. 2013;34(5):1035-1039.
12. Kim JH, Chung J, Huh SK, et al. Therapeutic strategies for residual or recurrent intracranial aneurysms after microsurgical clipping. *Clin Neurol Neurosurg*. 2018;173:110-114
13. Gawlitza M, Soize S, Januel A-C, et al. Treatment of recurrent aneurysms using the Woven EndoBridge (WEB): anatomical and clinical results. *J Neurointerv Surg*. 2018;10(7):629 LP - 633. doi:10.1136/neurintsurg-2017-013287
14. Pierot L, Moret J, Barreau X, et al. Safety and efficacy of aneurysm treatment with WEB in the cumulative population of three prospective, multicenter series. *J Neurointerv Surg*. 2018;10(6):553-559. doi:10.1136/neurintsurg-2017-013448

15. Caroff J, Mihalea C, Dargento F, et al. Woven Endobridge (WEB) Device for endovascular treatment of ruptured intracranial wide-neck aneurysms: a single-center experience. *Neuroradiology*. 2014;56(9):755-761. doi:10.1007/s00234-014-1390-7
16. Asnafi S, Rouchaud A, Pierot L, Brinjikji W, Murad MH, Kallmes DF. Efficacy and Safety of the Woven EndoBridge (WEB) Device for the Treatment of Intracranial Aneurysms: A Systematic Review and Meta-Analysis. *AJNR Am J Neuroradiol*. 2016;37(12):2287-2292. doi:10.3174/ajnr.A4900
17. Lawson A, Goddard T, Ross S, Tyagi A, Deniz K, Patankar T. Endovascular treatment of cerebral aneurysms using the Woven EndoBridge technique in a single center: preliminary results. *J Neurosurg*. 2017;126(1):17-28. doi:10.3171/2015.4.JNS142456
18. Lawson A, Molyneux A, Sellar R, et al. Safety results from the treatment of 109 cerebral aneurysms using the Woven EndoBridge technique: preliminary results in the United Kingdom. *J Neurosurg*. 2018;128(1):144-153. doi:10.3171/2016.9.JNS152849
19. van Rooij SBT, van Rooij WJ, Peluso JP, et al. WEB Treatment of Ruptured Intracranial Aneurysms: A Single-Center Cohort of 100 Patients. *AJNR Am J Neuroradiol*. 2017;38(12):2282-2287. doi:10.3174/ajnr.A5371
20. Gawlitza M, Soize S, Manceau P-F, Pierot L. An update on intrasaccular flow disruption for the treatment of intracranial aneurysms. *Expert Rev Med Devices*. 2019;16(3):229-236. doi:10.1080/17434440.2019.1584035
21. Mihalea C, Caroff J, Pagiola I, et al. Safety and efficiency of the fifth generation Woven EndoBridge device: technical note. *J Neurointerv Surg*. January 2019. doi:10.1136/neurintsurg-2018-014343

22. Lubicz B, Klisch J, Gauvrit J-Y, et al. WEB-DL endovascular treatment of wide-neck bifurcation aneurysms: short- and midterm results in a European study. *AJNR Am J Neuroradiol*. 2014;35(3):432-438. doi:10.3174/ajnr.A3869
23. Ahmed SU, Mocco J, Zhang X, et al. MRA versus DSA for the follow-up imaging of intracranial aneurysms treated using endovascular techniques: a meta-analysis. *J Neurointerv Surg* 2019; May 2 [Epub ahead of print]
24. Timsit C, Soize S, Benaissa A, Portefaix CJ.-Y. Gauvrit J.-Y., Pierot L. Contrast-Enhanced and Time-of-Flight MRA at 3T Compared with DSA for the Follow-Up of Intracranial Aneurysms Treated with the WEB Device. *AR Am J Neuroradiol*. 2016, 37 (9) 1684-1689; DOI: <https://doi.org/10.3174/ajnr.A4791>
25. Mine B, Tancredi I, Aljishi A, et al Follow-up of intracranial aneurysms treated by a WEB flow disrupter: a comparative study of DSA and contrast-enhanced MR angiography. *J Neurointerv Surg* 2015 May 21. [Epub ahead of print] doi:10.1136/neurintsurg-2015-011644 pmid:25999378
26. Slater LA, Soufan C, Holt M, et al. Effect of flow diversion with Silk on aneurysm size: a single-center experience. *Interv Neuroradiol* 2015;21:12–18
27. Shapiro M. Neurovascular topics in the endovascular arena. SAM- vascular-audience response (AR) self-assessment module (SAM). In: Proceedings of the Annual Meeting of the American Society of Neuroradiology, Long Beach, California. April 22–27, 2017
28. Rabinstein A, Nichols DA Endovascular coil embolization of cerebral aneurysm remnants after incomplete surgical obliteration. *Stroke*. 2002;33:1809–1815
29. Kivelev J, Tanikawa R, Noda K, et al. Open surgery for recurrent intracranial aneurysms: techniques and long-term outcomes. *World Neurosurg* 2016;96:1–9.

30. De Leacy A, Fargen KM, Mascitelli JR, et al. Wide-neck bifurcation aneurysms of the middle cerebral artery and basilar apex treated by endovascular techniques: a multicentre, core lab adjudicated study evaluating safety and durability of occlusion (BRANCH) *J Neurointerv Surg* 2018;0:1-6
31. Fiorella D, Arthur AS, Chiacchierini R, Emery E, Molyneux A, Pierot L et al. How safe and effective are existing treatments for wide-necked bifurcation aneurysms? Literature-based objective performance criteria for safety and effectiveness. *J Neurointerv Surg* 2017;9:1197-1201
32. Kim SJ and Choi IS Midterm outcome of partially thrombosed intracranial aneurysms treated with guglielmi detachable coils *Interv Neuroradiol* 2000 Mar; 6(1): 13–25.
33. Gawlitza M, Januel AC, Tall P, et al. Flow diversion treatment of complex bifurcation aneurysms beyond the circle of Willis: a single-center series with special emphasis on covered cortical branches and perforating arteries. *J Neurointerv Surg* 2016;8:481–7.
34. Bodily KD , Cloft HJ, Lanzino G, Fiorella DJ, White PM, Kallmes D Stent-assisted coiling in acutely ruptured intracranial aneurysms: a qualitative, systematic review of the literature *AJNR Am J Neuroradiol*. 2011;32:1232–1236
35. Pierot L, Boulin A, Visot A, et al. Postoperative aneurysm remnants: endovascular treatment as an alternative to further surgery. *Neuroradiology* 1999;41:315–9.
36. National Institute for Health and Care Excellence. Interventional procedures guidance [IPG658]. 2019. <https://www.nice.org.uk/guidance/ipg658/chapter/1-Recommendations>. Accessed Feb 10, 2020
37. Leyon JJ, Chavda S, Lamin S Corking the WEB and coiling through a jailed microcatheter: WEB assisted coiling, a useful technique avoiding the use of stents in

- treating wide-necked large intracranial aneurysms. *BMJ Case Rep* 2015 May 2;2015. pii: bcr2015011649. doi: 10.1136/bcr-2015-011649.
38. Anil G, Goddard AJP, Ross SM, Deniz K, Patankar T. WEB in Partially Thrombosed Intracranial Aneurysms: A Word of Caution. *Am J Neuroradiol.* 2016;37(5):892 LP - 896. doi:10.3174/ajnr.A4604
39. Chapot R, Gonzalez AV Apologia of transparency: answer to the letter of L Pierot. *Neuroradiology.* 2019;61:245-246
40. Pierot L Wide-neck aneurysms: which technique should we use? *Neuroradiology.* 2019;61:243-244
41. Pierot L, Arthur AS, Fiorella D, Spelle L. Intracapsular Flow Disruption with WEB Device: Current Place and Results in Management of Intracranial Aneurysms. *World Neurosurg.* 2019;122:313-316. doi:10.1016/j.wneu.2018.11.130

FIGURES:

Figure 1. Panel of images showing an aneurysm that was re-treated with WEB implantation following an unsuccessful attempt at surgical clipping (Patient 1).

A patient in their 50s presented with a single seizure. They were hypertensive, had chronic obstructive pulmonary disease and had a 40-pack year smoke history. A left MCA bifurcation aneurysm was discovered on MRI and characterization with CTA showed a partially thrombosed, 21 mm (maximal diameter) aneurysm with a 5 mm wide neck (A, B). The decision of the neurovascular multidisciplinary team (MDT) and patient was for surgical clipping. A mixed atheromatous and calcified plaque at the aneurysmal neck extending into the temporal M2 segment was seen at surgery (C) prevented a safe clipping due to the risk of emboli and the risk of occlusion of the temporal M2 segment. Muslin wrapping was performed instead. The aneurysm was unchanged on DSA, and after MDT and patient discussion, underwent WEB implantation 3 months later. A 6 Fr Shuttle catheter (Cook Medical, Indiana, USA), a 0.072" Navien intracranial support catheter (Medtronic, Dublin, Ireland) and a 0.027" Via microcatheter (Microvention, Tustin, USA) were used to deploy a single layer 6 mm (width) x 4 mm (height) WEB SL device into the neck of the aneurysm as a cork (D). Adjunctive coils were placed into the distal sac (D) through a 1.7 Fr Echelon-10 microcatheter (Medtronic, Dublin, Ireland). Aspirin 75 mg PO OD was given before, during and after all procedures (prescribed independently for cardiovascular risk). Heparin was given at the beginning (5000 IU IV), end (3000 IU IV) and following the procedure (1000 IU/h IV over 20 h). Complete occlusion of the aneurysm was shown at the end of the procedure with normal filling of the left MCA circulation. There were no complications periprocedurally or during 18-month follow-up. Six and 18 month check 3D TOF MRA confirmed persisting complete occlusion.

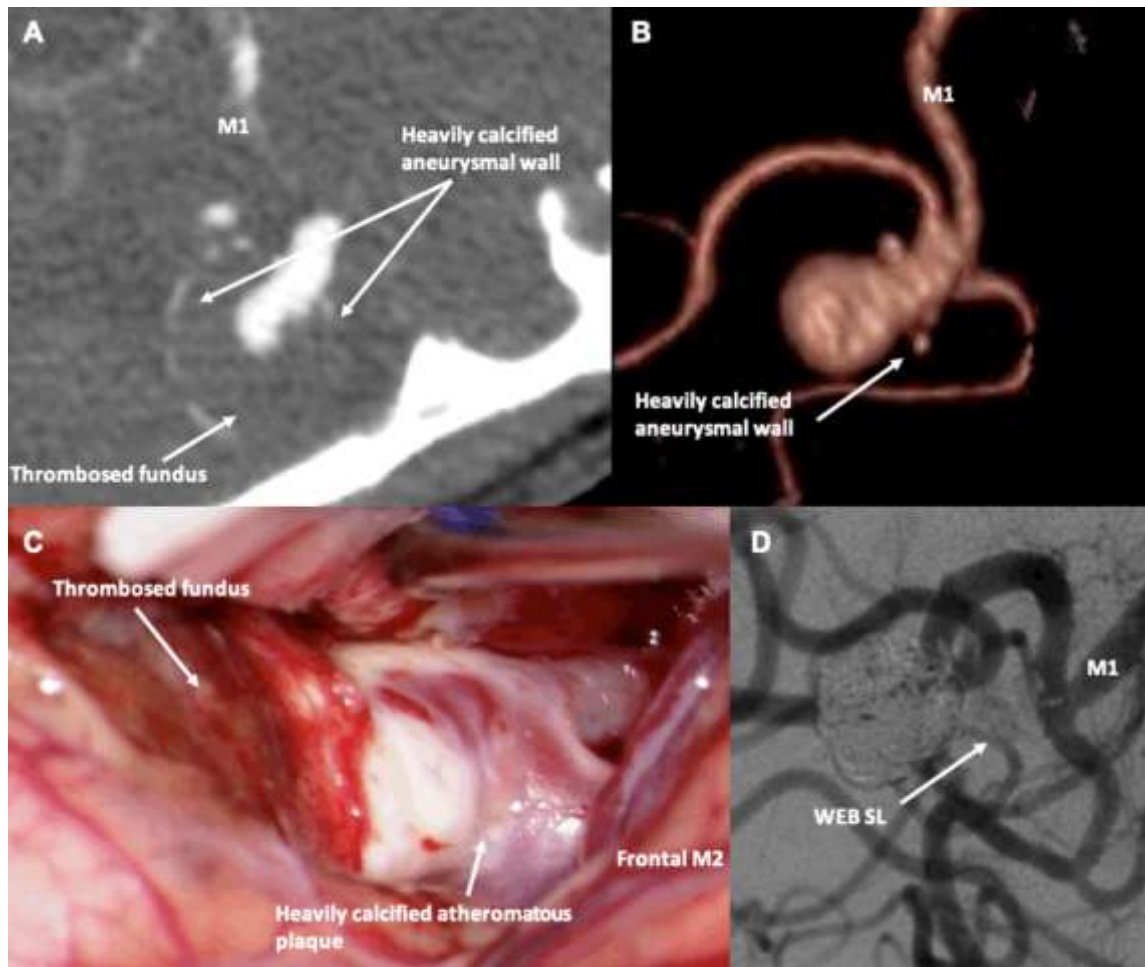


Figure 2. Panel of images showing an aneurysm that was re-treated with WEB implantation following incomplete surgical clipping (Patient 4). A patient in their 50s was referred for treatment after incidental discovery of a right MCA bifurcation aneurysm. The patient was hypertensive and a smoker. Cone-beam CT angiography (DynaCTA) showed a 8 mm (maximal diameter) aneurysm with a 6 mm wide neck (A). The decision of the MDT and patient was for surgical clipping. The procedure was complicated by difficulty of clip placement due to impaired visualization of neck M2 branches and a bloody operative field. Intra-operative fluorescence angiography demonstrated that neck coverage, whilst incomplete, gave adequate occlusion. The patient developed an ischemic infarct within the operated territory. (B) Follow-up DSA showed that the aneurysm remained almost identical. The case was reassessed in the MDT

and after discussion with the patient, WEB implantation was planned 2 months after clipping. A 6 Fr Envoy catheter (Codman, Raynham, USA), a 0.058" Navien intracranial support catheter (Medtronic, Dublin, Ireland) and a 0.027" Via microcatheter (Microvention, Tustin, USA) were used to deploy a single layer 7 mm (width) x 5 mm (height) WEB SL device (C). The patient was commenced on aspirin 150 mg PO OD and clopidogrel 150 mg PO OD 3 days before the procedure. 5000 IU heparin IV was given at the beginning of the procedure. Complete occlusion of the aneurysm was shown at the end of the procedure with normal filling of the right MCA circulation (C). There were no new complications periprocedurally or during 24-month follow-up. Six and 24 month check cone-beam CT angiography confirmed persisting complete occlusion.

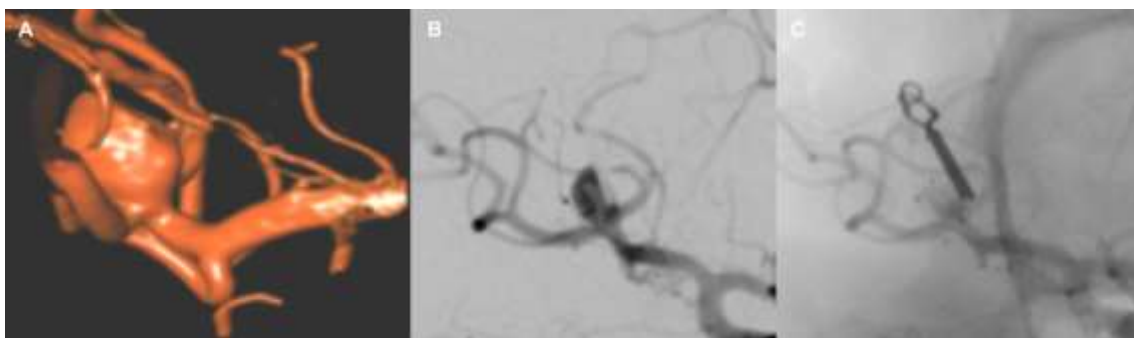


Figure 3. Panel of images showing an aneurysm whose morphology changed after incomplete surgical clipping allowing re-treatment with WEB implantation (Patient 5).

A patient in their 50s presented with a WFNS grade 1 subarachnoid hemorrhage due to a ruptured 9 mm (maximal diameter) right MCA bifurcation aneurysm with a 5 mm neck, shown here on an CTA reformat (A). The decision of the MDT and patient was for surgical clipping. Surgery was performed using intra-operative fluorescence angiography and the clipping was uneventful. (B) However, at 2 month DSA follow-up there was a 4

mm (maximal diameter) aneurysm remnant with a 4 mm wide neck, shown here as an unsubtracted image where the morphology was now more suitable for WEB implantation. The case was reassessed in the MDT and after discussion with the patient, WEB implantation was performed. A 6 Fr Benchmark catheter (Penumbra, Alameda, USA) and a 0.021" Via microcatheter (Microvention, Tustin, USA) was used to deploy a single layer 5 mm (width) x 3 mm (height) WEB SL device (C). The patient was commenced on aspirin 300 mg aspirin and clopidogrel 300 mg the evening before and the morning of the procedure. 5000 IU heparin IV was given at the beginning of the procedure. (D) Adequate occlusion of the aneurysm was shown at the end of the procedure with normal filling of the right MCA circulation. There were no new complications periprocedurally or during 24-month follow-up. Six and 8 month DSA confirmed persisting adequate occlusion.

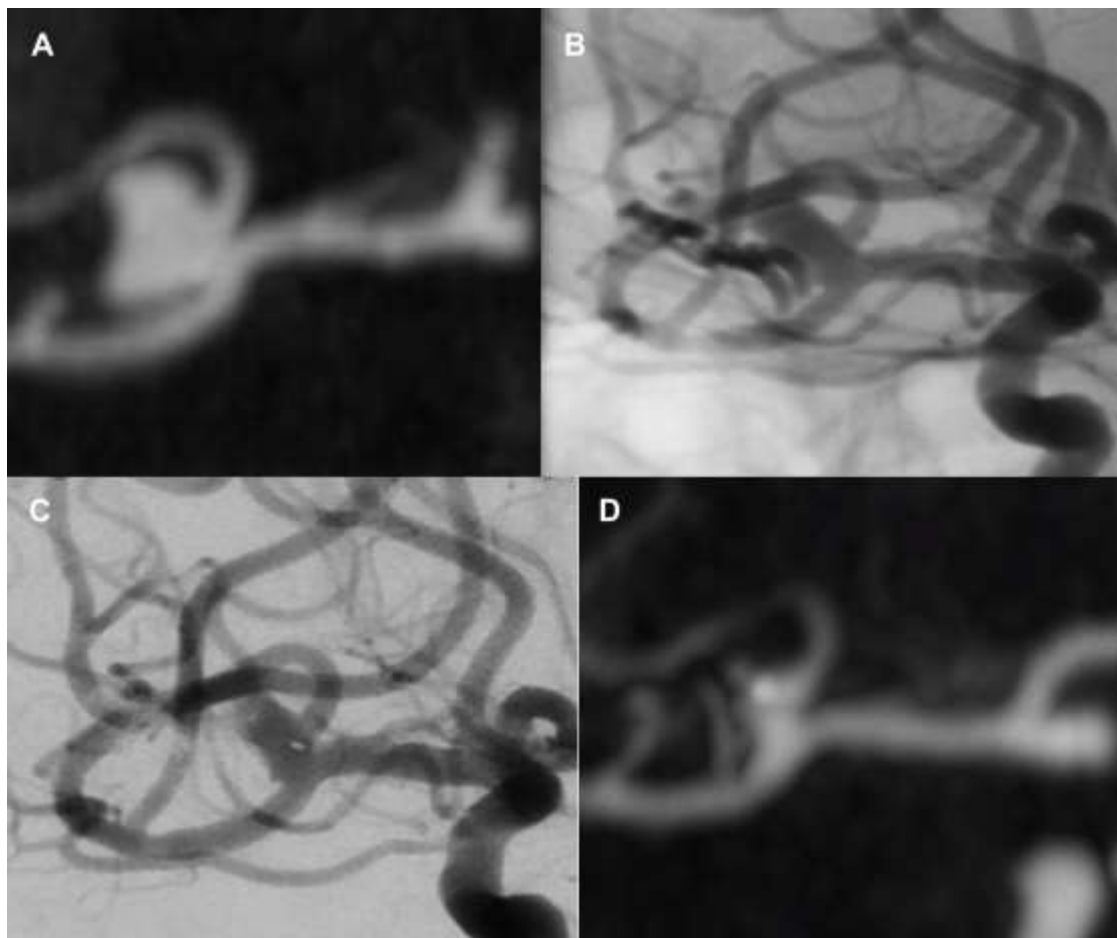
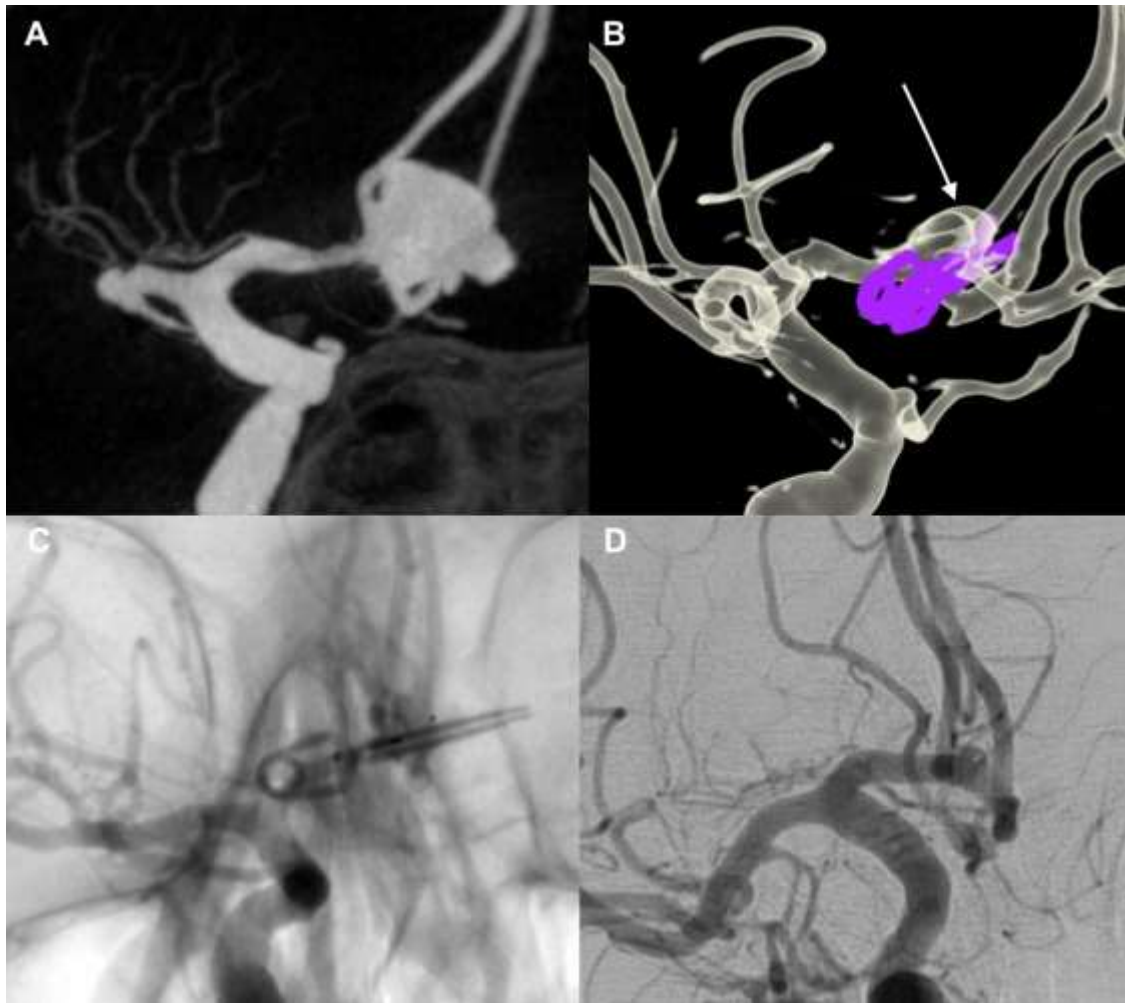


Figure 4. Panel of images showing an aneurysm whose size changed after incomplete surgical clipping allowing re-treatment with WEB implantation (Patient 6).

A patient in their 60s presented with a WFNS grade 1 subarachnoid hemorrhage due to a ruptured 11 (maximal diameter) anterior communicating artery complex bifurcation aneurysm with an 8 mm neck, shown here on an CTA reformat (A). The decision of the MDT and patient was for surgical clipping. Surgery was performed using intra-operative fluorescence angiography and the clipping was uneventful. (B) However, at 7 day DSA follow-up there was a 4 mm (maximal diameter) aneurysm remnant (arrow) with a 4 mm wide neck, shown here as a cone-beam CT angiography reformat (clip is purple). The aneurysm morphology was now suitable for WEB implantation. The case was reassessed in the MDT and after discussion with the patient, WEB implantation was performed the same day. A 6 Fr Benchmark catheter (Penumbra, Alameda, USA) and a 0.021" Via microcatheter (Microvention, Tustin, USA) was used to deploy a single layer 5 mm (width) x 3 mm (height) WEB SL device (C). 5000 IU heparin IV was given at the beginning of the procedure and 500 mg aspirin IV was given after WEB implantation. Aspirin 75 mg PO OD was given after the procedure for 6 weeks. Complete occlusion of the aneurysm was shown at the end of the procedure with normal filling of the right MCA circulation. There were no new complications periprocedurally or during 16-month follow-up. Three and 6 month DSA confirmed persisting complete occlusion (D) (adjacent to the WEB there is en face branch origin which is not to be confused with a neck remnant).



TABLES:

Table 1: Baseline patient characteristics and pre-clipping aneurysm features

	Patient 1	Patient 2	Patient 3	Patient 4	Patient 5	Patient 6
Age (decades)*	50s	40s	60s	50s	60s	50s
Aneurysm risk factors	HTN Smoker			HTN Smoker	Smoker	
Other medical history	COPD				Breast cancer	
Baseline mRS	0	0	0	0	0	0
Clinical presentation	Mass effect (seizure)	Incidental	SAH	Incidental	SAH	SAH
Aneurysm localization	Left MCA Bifurcation	Acomm Complex	Left MCA Bifurcation	Right MCA Bifurcation	Right MCA Bifurcation	Acomm Complex
Maximal sac diameter (mm)	21	15	9	8	9	11
Neck width (mm)	5	9	6	6	5	8
Ruptured aneurysm	No	No	Yes	No	Yes	Yes
Thrombosed aneurysm	Yes	Yes	No	No	No	No

HTN: arterial hypertension; COPD: chronic obstructive pulmonary disease; mRS: modified Rankin Scale;

SAH: subarachnoid hemorrhage; MCA: middle cerebral artery; Acomm: anterior communicating artery.

* Decades given rather than specific age; and individual sex not given, in order to maintain the highest degree of anonymity. There were 3 female and 3 male patients.

Table 2: Time between the first clipping treatment and WEB implantation re-treatment; and pre-WEB implantation clinical and aneurysm features

	Patient 1	Patient 2	Patient 3	Patient 4	Patient 5	Patient 6
Time from clip treatment to WEB re-treatment (days)	90	2	2	60	60	7
Post-clipping mRS	0	0	1	2	0	0
Maximal sac diameter (mm)	21	15	9	8	4	4
Neck width (mm)	5	9	6	6	4	4
Thrombosed aneurysm	Yes	Yes	No	No	No	No

mRS: modified Rankin Scale

Table 3: Periprocedural complications and follow-up

	Patient 1	Patient 2	Patient 3	Patient 4	Patient 5	Patient 6
Periprocedural complications	No	No	No	No	No	No
Brain ischemia	No	No	No	No	No	No
Hemorrhage	No	No	No	No	No	No
Post-WEB immediate mRS	0	0	1	2	0	0
Aneurysm appearance post device placement	Undergoing thrombosis to give complete occlusion	Undergoing thrombosis to give neck remnant (WOS 3)	Undergoing thrombosis to give neck remnant (WOS 3)	Undergoing thrombosis to give complete occlusion	Undergoing thrombosis to give neck remnant (WOS 3)	Undergoing thrombosis to give complete occlusion

	(WOS 2)			(WOS 2)		(WOS 2)
Follow-up mRS	0 at 6 & 18 months	0 at 6 & 18 months	1 at 3 & 8 months	2 at 6 & 24 months	0 at 6 & 8 months	0 at 3 & 16 months
Follow-up Imaging findings	Complete occlusion (WOS 2) at 6 & 18 months MRA	Neck remnant (WOS 3) at 6 & 18 months MRA	Neck remnant (WOS 3) at 3 months DSA & sac remnant (WOS 4) at 8 months MRA	Complete Occlusion (WOS 2) at 6 & 24 months DSA with cone-beam CT angiography (DynaCTA)	Neck remnant (WOS 3) at 6 & 8 months DSA	Complete Occlusion (WOS 2) at 3 & 16 months DSA

WEB Occlusion Scale (WOS)